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UNITED STATES
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BUREAU OF MINES
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INFORMATION CIRCULAR

LIGHTWEIGHT AGGREGATES FOR CONCRETE

BY

FORREST T. MOYER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

LIGHTWEIGHT AGGREGATES FOR CONCRETE 1/

By Forrest T. Moyer 2/

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GENERAL

Need for lightweight building materials was created in the latter part of the nineteenth century by a radical change in building design in which dead load or structural weight was transferred from thick, heavy, load-bearing walls of former construction practice to a load-carrying framework of beams and columns with thin walls. This new design was brought about by the introduction of structural steel followed by reinforced concrete and structural concrete as materials for the erection of the load-supporting frame. The new materials and method of construction made possible the erection of skyscrapers and the building of bridges with long spans, and made feasible additions of one or more floors to existing buildings.

As size and design of the load-bearing framework are controlled chiefly by dead load, the natural result was a search for and use of light-weight materials in partitions, floors, and exterior walls. However, these thin walls created problems of heat and sound insulation, so that building materials which possessed good heat- and sound-insulating properties in addition to light weight were objects of extensive research. One group of materials developed to fill this need comprised lightweight concretes, of which some were obtained by the use of lightweight aggregates.

Although the advantages of lightweight materials were evident from the first skyscrapers, there was a transition stage between the old bearing-wall and modern skeleton-frame types of building, with the heavy and massive construction of the former superimposed upon the latter. Hence, it was not until the period between 1910 and 1930 that the new lightweight concretes were recognized and used more extensively in the erection of large, nonresidential buildings. From this type of construction, light-weight-aggregate concretes entered fields of residential and small non-residential building, in which they were found desirable for production of prefabricated, large-size, masonry units. Although the weight of each unit was reduced sufficiently to enable one man to handle it easily, properties of the new concretes other than light weight were the principal factors in the ready acceptance of these new materials in residential building.

Manufacture of precast units includes complete lines of masonry and back-up blocks, bricks, floor beams, columns and partition, roof, and floor tiles and slabs. Recent improvements in casting machinery, development of the vibration-pressure machine, and a more thorough study and knowledge of the requirements and properties of the concrete mix have all contributed materially to the rapid expansion in use of lightweight aggregates in this industry.

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The object of the following discussions is to present briefly the development, method of manufacture, properties, uses, and present economic status of the more common lightweight aggregates used in concrete. Information was obtained chiefly by correspondence and by visits with the personnel of producing companies, and the writer is indebted to many individuals in all phases of the lightweight-aggregates industry for their courtesy in supplying data. Publications concerning the various aggregates are listed in footnote references and in the reference section at the end of this report.

KINDS OF AGGREGATES

Lightweight aggregates may be classified into three general groups, depending upon their source: (1) Natural, (2) byproduct, and (3) specially processed materials. Natural substances include volcanic scoria, pumice, and diatomaceous earth; byproduct aggregates are air-cooled slags, cinders, sawdust, and coke breeze; and the third group contains the expanded shales or clays and slags, nearly all of which are marketed under patented trade names.

GENERAL PROPERTIES AND USES

All lightweight aggregates impart essentially the same characteristics in varying degrees to the finished concrete in which they are used. Light weight, nailability, ease of cutting or channeling, and adequate heat- and sound-insulation of the finished work are the principal desirable properties. In effectiveness they vary inversely with the weight per cubic foot of the finished concrete. These aggregates find use in many types of construction wherever any one or a combination of the foregoing properties is sought.

The largest outlet for lightweight aggregates is in the manufacture of all types of precast building units in which nailability, ease of channeling, and heat- and sound-insulation are the properties desired. In the construction of large buildings, the light weight of the finished concrete is essential, but in residential construction it is merely advantageous.

In poured-concrete construction these aggregates have been found satisfactory for use in the floors of drawbridges, long bridge spans, and large buildings, and as a fireproof covering surrounding the load-bearing, structural-steel frame. In instances in which an existing building was designed originally for later addition of one or more floors it has been found that the reduction in dead weight obtained by the use of lightweight-aggregate concrete permits the addition of more floors than was originally planned without changing the foundations. The heat- and sound-insulating properties of this type of concrete are important for virtually all of its uses in building construction.

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NATURAL AGGREGATES

Vesicular volcanic materials are the principal natural lightweight aggregates. Of these, pumice is the most important, although scoria, cinders, breccia, and tuff also are suitable for use as aggregate. Other lightweight substances that are suitable in their natural form include diatomite and anthracite.

Pumice and Other Volcanic Materials

Pumice, scoria, volcanic cinders, breccia, and tuff are the only common rocks light and strong enough to be classed as lightweight aggregates. Pumice and scoria are vesicular lavas in which the cells are formed by the gases escaping from the molten material. Scoria usually has a dark color and contains larger and more irregularly shaped cells than pumice, which is light-colored and has a fairly even texture of small cells. Volcanic cinders are rough fragments of vesicular lava either erupted from a volcano or formed by shattering of the crust of a lava flow through rapid cooling. Volcanic breccia and tuff are porous, crudely stratified, more-or-less consolidated rocks consisting of cinders and ash erupted from nearby volcanos. Beds composed largely of coarse fragments are termed breccia, and those of fine material are tuff. Pumicite, an air- or water-deposited accumulation of powdered volcanic dust or ash, is usually too fine to be used as aggregate for concrete. Although lightweight volcanic materials are common in the Pacific Coast and Rocky Mountain States, many deposits are valueless owing to inaccessibility from transportation and markets or to the wide variations in physical characteristics of the contained material.

Pumice undoubtedly is the oldest known lightweight aggregate. During the renowned Roman building period in the first centuries B. C. and A. D., fragments of pumice 3 to 6 inches in size were used as aggregate to reduce dead weight in the construction of many of the great domes such as that of the Pantheon, and of the immense vaults of the public baths in Rome. Little is known of its use from that time until shortly after the middle of the last century, when pumice-concrete was introduced in the Nette and Brohl Valleys in Germany. The pumice aggregate was obtained from local deposits, and the concrete proved so satisfactory that its use for lightweight construction spread through other European countries.

Until recently, operators of pumice deposits in the United States regarded sales of the material for aggregate purposes merely as an adjunct to the operations necessary to obtain abrasive-grade pumice and did not attempt to develop the aggregate market. The low sales price per unit of pumice aggregate necessitates large-scale operations, and both of

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these factors are in contradiction to the relatively high price and selective mining of the established abrasive-pumice trade. Hence, sales for aggregate use were sporadic and usually small.

Thus far nearly all of the domestic production of pumice aggregate has been from operations in California, but recently deposits in Colorado, Idaho, New Mexico, Oregon, and Utah have been worked to supply nearby block manufacturers. In Arizona and several other Rocky Mountain States tuff deposits have been quarried for local consumption as building stone, but so far as known the material has not been used for aggregate. Pumice also is used locally as building stone.

The first large-scale use of pumice for concrete aggregate in this country was begun in 1935 near Napa, Calif., at the north end of San Francisco Bay. The excavated pumice is passed through a hammer mill and screened to two aggregate sizes, 7/16- to 1/8-inch and 1-8-inch to 50-mesh, which are used to make precast building units. Fines passing 50-mesh are dried and ground for use as filler. Concrete used to make the complete line of wall, floor, and roof units has an average weight of 80 pounds per cubic foot. A standard 8- by 8- by 16-inch masonry unit weighs about 30 pounds. All units are sold under the trade name "Basalite" and have the desirable properties given by the lightweight mixture. Acoustical units and slabs are made with pumice concrete that weighs approximately 50 pounds per cubic foot - a weight attained by grading of the aggregate. Sand sizes of pumice are used as part of the aggregate in the concrete-mix from which roofing shingles are cast.

Concrete made with pumice aggregate obtained from the Medicine Lake section of Siskiyou County, Calif., weighed 70 to 75 pounds per cubic foot when mixed as follows: 1 part cement, 2 parts pumice sand (minus 1/8-inch material), and 4 parts coarse aggregate (1/8- to 3/4-inch material). Pebble pumice from Friant, Calif. makes concrete weighing 90 pounds per cubic foot and is used by block manufacturers in Oakland, Fresno, Modesto, and other nearby cities. A reddish volcanic cinder from Millard County, Utah, is employed at Provo to make a standard masonry unit weighing only 28 pounds. Similar units made with reddish volcanic cinder at Blackfoot, Idaho, average 30 pounds in weight.

Diatomite

This material is essentially hydrated amorphous silica consisting of the porous skeletal remains of microscopic aquatic plants called diatoms. Pure diatomite has an average weight of 28 pounds per cubic foot, but impurities such as sand or clay greatly increase the unit weight. Large deposits exist in California, Oregon, Nevada, Washington, and several of the Eastern Coastal States.

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The diatomite product known as Sil-O-Cel C-3 is used as an aggregate in concrete for special high-temperature insulations on furnaces. For this use granules of either natural or calcined material are crushed to pass a 4-mesh sieve and mixed with portland or refractory cements in varying proportions. Concrete of a 1:5 mix by weight will average about 60 pounds to the cubic foot. Diatomite aggregates of this type have a loose weight of 20 to 30 pounds per cubic foot.

Impure diatomite and diatomaceous shales have been made into lightweight aggregates by patented processes described later in this report under "Processed Aggregates."

Anthracite

Anthracite, which weighs 90 to 95 pounds per cubic foot, has been used experimentally as concrete aggregate with satisfactory results. However, such practice is not economical, as coal in aggregate sizes is too costly.

BYPRODUCT AGGREGATES

The most important byproduct lightweight aggregates are air-cooled slags and coal cinders, both of which have been used widely in concrete construction and in precast building units. Coke breeze, the fine screenings obtained in sizing metallurgical and household coke, is included in this group. Sawdust, which has had only limited use in the United States, is also included.

Air-Cooled Slags

Slag is the nonmetallic product consisting essentially of calcium silicates and aluminosilicates formed as a byproduct in the smelting of iron and other ores. Although not strictly a lightweight aggregate, air-cooled slag is included here because concrete made with it has an average weight of 135 pounds per cubic foot - 10 to 20 pounds lighter than rock-sand concrete. The expanded slags in which lightweight is obtained purposely by treatment with water or steam will be described later in the section on specially-processed aggregates.

The common methods of producing air-cooled slag are by the pit or modified-pit systems, in which the molten material from the furnace is run directly or conveyed and poured into a series of connected pits. The molten slag spreads over the bottom of the pits in a thin layer and hardens rapidly, thereby trapping the gases and forming a somewhat cellular structure. Succeeding layers are run or poured until the pits are full,

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after which the layered material is removed easily by power shovels without resorting to blasting. Broken slag from the pits is passed over a magnetic separator to remove pieces of iron and is crushed and screened to aggregate sizes by standard equipment. Slag aggregates are obtained also by crushing and sizing material broken loose from old slag banks.

Individual pieces of air-cooled slag are rough-surfaced due to the cellular structure, are angular and roughly cubical, and have a light-to dark-gray color. The weight of compacted, dry, aggregate-sized slag ranges from 65 to 100 pounds and averages 80 pounds per cubic foot. In dry, loose condition the weight is less by about 10 pounds per cubic foot. Apparent specific gravity averages 2.25, as compared with the true specific gravity of about 3.05. Average absorption is 4 percent by weight, so that slightly more mixing water is required for concrete containing slag than that containing gravel or stone aggregates. In composition a general range that covers virtually all blast-furnace slags in the United States would be SiO_2, 32 to 40 percent; Al_2O_3, 10 to 17 percent; CaO, 30 to 49 percent; MgO, 3 to 14 percent; FeO, 0.5 to 2 percent, and S, 1 to 2 percent.

With regard to stability and durability, exhaustive tests and actual use for more than 50 years have shown that concretes made with slag aggregates free from dusting are as satisfactory as common rock-sand concretes. Dusting, which is believed to be caused by the presence of dicalcium silicate, usually is not exhibited by slags containing less than 40 to 42 percent CaO or by quickly cooled slags.

Chief sources of supply of air-cooled slags are the major iron-smelting centers of the country in the Pittsburgh (Pa.), Chicago-Gary (Ill. and Ind.), Cleveland-Youngstown (Ohio), Detroit (Mich.), Birmingham (Ala.), Wheeling (W. Va.), Pueblo (Colo.), Provo (Utah), Johnstown (Pa.), Baltimore (Md.), Buffalo (N. Y.), and eastern Pennsylvania districts. In addition, any active iron blast-furnace or slag bank of an abandoned operation is a possible source of the aggregate.

Results of an annual canvass by the National Slag Association showed that 34 companies operating 70 plants in 1940 sold or used 9,363,228 short tons of air-cooled, blast-furnace slag - a gain of 28 percent over the tonnage reported for 1938. Although approximately three-fourths of the slag is processed in Alabama, Ohio, and Pennsylvania, the material is marketed in all States east of the Mississippi except some New England States, which are too remote from sources of supply. The use of air-cooled slag as aggregate in concrete for highway and building construction consumed 1,867,398 short tons or 20 percent of the 1940 supply. Consumption by other uses is given in table 2.

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TABLE 1. - Air-cooled blast-furnace slag sold or used by producers in the United States, 1938-40, by States 1/

State	1938		1939		1940	
	Short tons	Value	Short tons	Value	Short tons	Value
Alabama	1,852,236	$1,173,890	2,285,317	$1,399,612	2,609,273	$1,718,872
Ohio	2,533,088	2,403,341	2,560,748	2,205,144	3,021,039	2,647,087
Pennsylvania	1,247,101	1,237,616	1,125,748	1,014,859	1,363,002	1,295,579
Other States 2/	1,688,834	1,353,045	1,943,468	1,503,103	2,369,914	1,361,366
	7,321,259	6,167,892	7,920,281	3,122,718	9,363,228	7,522,904

1/ National Slag Association.
2/ Colorado, Illinois, Kentucky, Maryland, Michigan, New York, Tennessee, and West Virginia.

TABLE 2. - Air-cooled blast-furnace slag sold or used by producers in the United States in 1940, by uses 1/

	Unscreened			Screened	
	Short tons	Value		Short tons	Value	
		Total	Ave		Total	Ave
Concrete (pavements, buildings, bridges, etc.)	-	-	-	1,867,398	$1,501,929	$0.80
Roads other than concrete	237,602	$118,718	$0.50	4,358,680	3,999,041	.92
Railroad ballast	707,475	266,270	.38	1,167,339	774,828	.66
Mineral wool	2/	2/	2/	63,358	61,911	.98
Roofing	-	-	-	64,113	88,343	1.38
Fill and subbase cushion courses	122,449	38,600	.32	154,374	140,978	.91
Sewage trickle filter	-	-	-	122,471	97,449	.80
Airport runways	2/	2/	2/	2/	2/	2/
Roofing granules	-	-	-	2/	2/	2/
Agricultural purposes	-	-	-	32,242	30,076	.93
Other uses	172	69	.40	111,729	113,921	1.02
Use not given	88,094	36,103	.41	161,458	160,684	1.00
Total: 1940	1,230,832	507,288	.41	8,132,396	7,015,616	.86
1939	812,220	361,554	.45	7,108,031	5,870,582	.83
1938	1,202,754	567,224	.47	6,118,505	5,600,668	.92

1/ National Slag Association.
2/ Concealed to avoid revealing data of individual company; figures included in total.

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In recent years increasing quantities of the smaller sizes (minus-3/4-inch) are being used for manufacture of precast building units, particularly in the densely-populated eastern cities in which greater demand for large masonry units may have created a scarcity of cinders or other lightweight aggregate for block manufacture.

Cinders

The aggregate termed "cinders" is the residue from high-temperature combustion of coal or coke under forced draft in industrial furnaces. When thus limited, cinders consist chiefly of clinkers or fused, inorganic, cellular material with smaller percentages of ash or unfused inorganic material and unconsumed coal or coke. Clinkers and ash, which together comprise about 70 to 75 percent of the total, are composed largely of silica, alumina, lime, and iron oxides, with some magnesia, titanium oxide, and alkali and sulfur compounds. The remaining 25 to 30 percent of commercial cinder aggregate is unconsumed coal or coke.

Satisfactory service in construction for nearly 50 years has demonstrated the durability of cinder concrete and has shown that its use, when properly placed, does not aggravate corrosion of reinforcing or other embedded steel. Another old objection to the use of cinders (namely, lack of uniformity in quality) has been minimized by the primary producers, who now control the combustion processes so as to produce suitable cinders of uniform quality.

The physical characteristics of cinders are more important in judging suitability for aggregate purposes than are the chemical constituents. Relative quantities and characteristics of coal, coke, clinkers, and fine materials in the cinders, strength of coarse particle, and approximate grading should be observed from the physical appearance. In addition, chemical determinations of combustible, sulfide, and sulfate contents are important. Combustible content has surprisingly small influence on quality, but generally it is true that suitability of the cinders decreases as the combustibles increase. In the United States, specifications of the Underwriters' Laboratories limit the average combustible content of mixed fine and coarse cinders for manufacturing precast blocks to not more than 35 percent by weight of the dry, mixed aggregates.

In England expansion of cinder concrete under some conditions has been ascribed to certain types of unburnt or slightly burnt bituminous coals that are characterized by high rates of absorption of moisture and oxygen.3/

3/ Lea, F. M., and Desch, C. H., The Chemistry of Cement and Concrete: Arnold & Co., London, England, 1937, pp. 345-348.

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Not all English coals perform in this manner, and even the so-called "dangerous coals" lose this property when carbonized nearly to coke. A simple soundness test to detect injurious coal consists of mixing 3 parts by weight of minus-76-mesh cinder aggregate with 1 part of special cement composed of equal parts by weight of portland cement and gypsum plaster. The mixture is made plastic with water, spread into a pat 3 inches in diameter on a clean glass plate, and, after 3 to 4 hours in moist air, covered with water. If at the end of 4 days the edges of the pat are cracked or curled away from the plate, or if the pat is no longer cemented to the plate, the cinders are considered unsound and not suitable for use in concrete. In the United States there has been little trouble from "dangerous coals". It may be that coals of this type are of rare occurrence here or that the combustible content of bituminous-coal cinders is present as coke. Tests 4/on 57 commercial cinders by the above method showed all to be sound and suitable for aggregate use.

In Germany, expansion and cracking of set cinder concrete are said to be caused by the slaking of lime inclusions in the aggregate 5/ To detect harmful lime some crushed cinder is treated with White's reagent (5 gm. phenol in 5 cc. nitrobenzene plus 2 drops water) followed by examination with polarizing microscope for calcium phenolate crystals, which indicate presence of free lime.

Anthracite cinders differ somewhat in physical characteristics from those obtained by burning bituminous coal; but both are suitable for concrete, and neither is said to be superior to the other. In a dry, rodded condition cinders of both types, after crushing to pass a 3/4-inch opening, weigh about 60 pounds per cubic foot. Finished all-cinder concrete has an average weight close to 85 pounds per cubic foot. It is used largely for the manufacture of precast masonry blocks, a standard-size unit of which weighs about 30 pounds.

Sand-cinder concrete has been used extensively in some metropolitan areas as a lightweight structural concrete chiefly for floors of tall buildings. In this mixture cinders are used to decrease the weight, and sand is used to increase workability. It is also claimed that sand prevents segregation of the aggregates while the material is being placed. The most usual proportions of a sand-cinder concrete are 1:2:5, which yields a set product weighing 110 to 115 pounds per cubic foot. Recently this type of concrete has been batched at a central plant and is mixed while being transported to the job by truck.

4/ National Bureau of Standards, Cinder Aggregates for Concrete Building Units: Tech. News Bull. 181, May 1932, p. 47.

5/ Gonell, H. W., Clinker as Concrete Aggregate: Bantenschutz, vol. 8, No. 12, 1937, pp. 137-139.

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Although the extent to which cinders are used as aggregate is not known, it appears that they are employed for this purpose wherever supplies are available and that in some localities, particularly the Eastern States, cinders are an important building material. The use of structural-cinder and sand-cinder concretes reached maximum development in the large metropolitan areas of the Middle Atlantic States during the 1920's, when activity in "skyscraper" building was at a high level. Since 1932 most of the cinder aggregate has entered into manufacture of precast cinder building units, a branch of the concrete-masonry industry that grew phenomenally from 1919 to 1926. This growth resulted from the simple procedure of block-manufacture patented in 1917 (U. S. Patent 1,212,840), by which all of the cinder mass, pretreated only by crushing, is used as aggregate.

Coke Breeze

Coke breeze is the cellular minus-3/4-inch material obtained by screening metallurgical or household coke. It is composed mainly of combustible matter with a minor percentage of inorganic compounds grouped under the term "ash." Although coke breeze is sufficiently strong and durable, it is used for concrete aggregate only under exceptional circumstances, as the material has greater value for other purposes. Coke breeze concretes have an average weight of about 65 pounds per cubic foot and are said to show high shrinkage and absorption. Extensive experimental work and actual commercial production of precast units with coke-breeze aggregate were carried on in Nashville, Tenn., and Indianapolis, Ind.

Sawdust

The use of sawdust concrete in this country has been largely experimental, although in England and some sections of continental Europe its use for certain types of concrete-work is said to be fairly extensive. Concrete made with untreated sawdust is subject to appreciable expansion or contraction with changing humidity conditions. Numerous patented methods of pretreating the sawdust, usually by the addition of certain salts, have attempted to eliminate these movements, and concretes containing the "mineralized" sawdusts have been used in indoor and outdoor construction for such purposes as sidewalks, precast units for portable housing, flooring, subflooring, and precast building units and lumber. The coarse sawdust from soft woods (conifers, etc.) is preferred because particles of hardwood sawdust are likely to be too small and too uniform in size.

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Grog

Grog is a burned-clay material obtained by crushing and grinding imperfect or broken clay products. It has long been used in the ceramic industry as an addition to the raw clay mixture to reduce shrinkage and density. In recent years grog, derived from the manufacture of the newly developed insulating and lightweight brick, has been used as a lightweight aggregate in insulating concretes intended for use in temperatures up to 2,200° F. (1,200° C.). These concretes are used either directly exposed to the heat or as an insulating material to back up refractory brick.

PROCESSED AGGREGATES

Processed or manufactured lightweight aggregates are those obtained by treating raw materials to attain desired properties in products designed primarily for use as concrete aggregate. Widely varied types of patented manufacturing processes are employed. The aggregates belonging to this group have shown considerable growth in use in recent years. They may be divided into two main classes, namely, expanded shales or clays and expanded slags.

Expanded Shales or Clays

All expanded shale or clay aggregates are made by the same basic process, which essentially is the rapid elevation of the temperature of a prepared raw material to a point between its incipient and complete vitrification temperatures. In this temperature range, which is reached just before discharge from the kiln, the shale or clay softens, becomes sticky, and tends to trap evolved gases. The material is discharged in this condition and cooled rapidly to retain the cellular structure. Since raw shale or clay particles ranging in size from 48 mesh to 1 1/2 inches are fired together and all show the same degree of expansion, it is evident that the bloating occurs only after the material passes its temperature of incipient vitrification. Also, at this temperature the evolved gases are given off more rapidly than immediately prior to incipient vitrification, thereby indicating new source compounds from which the gases are derived. In the burning of bricks and formed clay products, it has been shown 6/ that black-coring and bloating, or expansion, are due to the carbon, iron, and sulfur contents of the raw materials. Sulfur is claimed to be the final or actual cause of the swelling, chiefly by the reactions of sulfides, sulfates, and silicates, to release sulfurous gases.

6/ National Brick Manufacturers' Association, The Status of Carbon, Iron, and Sulfur in Clays During the Various Stages of Burning: Third Rept., Committee on Technical Investigations, T. A. Randall & Co., Indianapolis, 1903, 108 pp.

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Because expanded-shale aggregates are fired much more rapidly than clay products, it is probable that the carbon, iron, and sulfur contents of the raw material all are important in the expansion phenomenon. Carbon and iron maintain a reducing atmosphere that conserves sulfur by preventing its early oxidation. In addition, carbon may provide some gases for expansion, and iron aids by forming low-melting-point silicates. The sulfur content provides gases for expansion at an increased rate when temperatures of 2,000° to 2,200° F. (1,100° to 1,200° C.) are reached. Also, a carbonate content probably is an additional source of gases at the vitrification range because dissociation or calcination of these compounds under the rapid firing schedule still would be in progress when the material softens. Presence of free lime in some expanded-shale aggregates indicates the rapid dissociation of carbonates after softening and before solidification of the discharge. In the patent literature a commonly suggested practice is to add small quantities of one or more of the foregoing substances to facilitate expansion of a clay or shale.

Clays and shales with short ranges of vitrification are claimed to be better-adapted to the manufacture of expanded aggregates than are those with long ranges. The latter soften gradually and thus permit escape of the evolved gases.

Cel-Seal

Cel-Seal, a pelletized, expanded-clay aggregate, is made by the process described in U. S. Patent 2,015,381, issued October 1, 1935. Introduced about 1930, it was known formerly under the trade names Globulite and Vesiculite, both of which have been abandoned. Thus far the aggregate has been made only experimentally in a rotary-kiln plant at Elephant Hill, Alhambra, Calif. A commercial plant utilizing red shale reportedly is planned near New Brunswick, N. J., to supply the New York and Philadelphia metropolitan areas.

In the manufacturing process low-fusion-point clay is mixed with small percentages of iron oxides and carbonaceous material and made plastic with water. It is then extruded through a multiple die as round pugs, which are cut into small billets by a rapidly-rotating wire as they leave the die. Size of the finished aggregate is controlled by diameters of the die-openings and speed of the cutting wire. The billets pass through a revolving cylinder, in which they are rounded and coated with powdered refractory clay that has a higher fusion temperature than the main body of the pellet. The pellets are expanded in a rotary kiln operated at a temperature above the fusion point of the center clay and below that of the coating. Although the centers expand to a cellular mass four to seven times the original volume,

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the coating remains fairly intact, is more dense then the center, and is partly vitrified but not fused. About 20 minutes are required for the burning operation. An alternate process (U. S. Patent 2,199,046, April 30, 1940) is to coat the pellets with oil or tar and to expand them by burning to a finished aggregate of individual pieces that have substantially uniform characteristics throughout.

The manufacturing process has been developed so that concrete aggregate can be made in sizes graded from 1/8-inch to 2 inches in diameter and in a number of weights from 15 to 30 pounds per cubic foot. Each particle is rounded or ellipsoid and in cross section shows a thin, rather smooth, dense, and tough outer layer surrounding a firm cellular interior. For load-bearing work a mixture of graded Cel-Seal aggregate and fine, natural sand yields a concrete weighing about 90 pounds per cubic foot. Non-load-bearing concrete as light as 50 pounds per cubic foot has been produced with this expanded aggregate.

Recent experimental work has developed an insulating-weight Cel-Seal aggregate that weighs as little as 3-3/4 pounds per cubic foot. Use of this extremely lightweight material as concrete aggregate should enlarge greatly the field of application of lightweight concrete. This insulating-weight aggregate has been used with other binders, such as gypsum and asphalt.

Gravelite

The aggregate "Gravelite" is made commercially by a patented process (U. S. Patent 2,035,845, March 31, 1936) in a rotary-kiln plant at Port Richmond, Calif. It is comprised of expanded-clay pellets, of which the coarse sizes weight 40 to 45 pounds and the sand size about 55 pounds per cubic foot in a saturated, surface-dry, loose condition.

In the process, clay or shale is ground, pugged, and forced through a multiple die, from which the extruded cylinders of clay are cut into pellets of the desired length. Only pellets of substantially uniform size are made at any one time. Sizes below 3/8-inch diameter are not molded but are processed by adding enough water in the pug mill to agglomerate the clay into small particles (minus-1/4-inch). The pellets or particles of a relatively narrow range in size are coated or sprayed with fuel oil and expanded by firing counter-flow in a rotary kiln. Discharge from the kiln is cooled and screened into 3 standard size ranges - minus-1/4-inch, 1/4- to 3/4-inch, and 3/4 to 1-inch.

The patent also includes the expansion of crushed and sized shale in the same equipment with omission of the grinding and pugging operations used for molded pellets.

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Concrete containing Gravelite as both fine and coarse aggregate weighs 75 to 85 pounds per cubic foot when dry. If most or all of the fine aggregate is sand and the coarse aggregate is Gravelite, the dry, set concrete weighs 95 to 100 pounds per cubic foot. The cured Gravelite-sand concrete used in the upper-deck floor of the San Francisco-Oakland Bay bridge weighed 95 to 97 pounds per cubic foot. Its use in place of crushed rock or gravel concrete on this bridge is said to have effected a saving of approximately 15,000 net tons in weight of concrete alone. The economic use of Gravelite concrete in buildings depends upon analysis of all factors, but under average conditions it is claimed[7/] that the additional cost over crushed stone or gravel aggregate is compensated in buildings of reinforced-concrete or steel-frame construction over seven stories in height. Above this height, over all construction costs are said to be lowered.

Gravelite concrete is an effective thermal insulator, as it has a K value (thermal conductivity) of only about 2.7 B.t.u. per square foot per hour per degree Fahrenheit for 1-inch thickness at 70° F. (21° C.). This property, combined with its nonspalling characteristic up to 1,800° F. (975° C.), makes Gravelite concrete an effective insulator for service temperatures up to about 1,600° F. (875° C.).

Haydite

Haydite, an expanded-shale aggregate, is made by a process first patented in February 1918 (U. S. Patent 11,255,878) and later improved as described in reissued United States Patent 1,707,395 of April 1929. These patents are assigned to the American Aggregates Co., Kansas City, Mo., which grants licenses to manufacture the aggregate.

Although the first sample was made in 1913, Haydite was not produced commercially until 1920. During the World War, however, free use of the patent was offered to the Federal Government to produce aggregate for construction of concrete ships, and extensive experimental work was done by the United States Emergency Fleet Corporation[8/]. Following pilot-plant tests in down-draft, dome kilns at Alton, Ala., in rotary kilns at Ragland, Ala., and in a tunnel kiln at Perth Amboy, N. J., the Corporation obtained its estimated requirements of 25,000 tons (or approximately 30,000 cubic yards) of lightweight aggregates from a rotary-kiln plant at Hannibal, Mo., and a down-draft, dome-kiln plant at Los Angeles, Calif. In dome kilns, Haydite was made by rapid

7/ Pike, Robert D., Concrete Aggregates--Gravelite: Rock Products, vol. 41, No. 8, August 1938, pp. 71-72.

8/ Engineering News-Record, History and Properties of Light-Weight Aggregates: Vol. 82, No. 17, April 24, 1919, pp. 802-805.

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burning of partly dried, stiff-mud bricks followed by crushing and sizing the expanded bricks. The rotary-kiln process was essentially the same as that employed today, except that the feed was crushed to smaller maximum size (100 percent through 50-mesh) and the discharge was crushed while still hot and partly vitrified so as to produce crudely-rounded particles.

After the war additional experiments were performed by private enterprise in a 3-1/2- by 25-foot rotary kiln in southern Kansas. The first commercial plant began operating in Kansas City, Mo., in 1920 and was followed by construction of two small-capacity plants at Salt Creek, Wyo., and Omaha, Neb. The latter two operations were short-lived. Other Haydite-manufacuring plants were built after 1925, and in 1941 there were eight active licensed operations at the following places in the United States and Canada:

San Rafael, Calif., McNear Co.
Danville, Ill., Western Brick Co.
East St. Louis, Ill., Hydraulic Press Brick Co.
Kansas City, Mo., Haydite Corporation.
Buffalo, N. Y., John H. Black Co.
Cleveland, Ohio, (South Park P. O.), Hydraulic Press Brick Co.
Bothel, Wash., Washington Haydite & Concrete Products Co.
Toronto, Ontario, Canada, Cooksville Co., Ltd.

A plant constructed near Large, Pa., in 1929 was operated for only a short time before being abandoned permanently.

Under the present method of manufacture, Haydite can be made from a great variety of shales and clays. In some plants the process is operated in conjunction with brick manufacturing, and in others only the aggregate is produced. The raw shale or clay from the quarry or bank is crushed to pass a 1-1/2-inch screen and then fed directly to a rotary kiln. Some processors set the maximum size as 1 inch, and those operating the process in connection with brick-making remove fines (minus-1/8- or 1/4-inch) from the kiln feed for use in the brick plant.

The rotary kilns for burning Haydite are commonly 50 feet in length and 6 feet in diameter and are pitched either 1 inch or 3/4-inch per foot. They are fired counterflow, usually by pulverized coal. Oil and natural gas also are satisfactory fuels. Kiln temperatures which are determined by the vitrification range of the raw material, are generally about 2,000° F. (1,100° C.) at the discharge end and 600° F. (300° C.) at the feed end. Most kilns have only one burner, from which the flame is directed approximately parallel to the kiln wall. On some kilns two burners are employed - one has its flame parallel to the wall, and the other is directed so that its flame is on the material about 2 feet inside the discharge end.

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The shale or clay remains in the kiln 30 to 40 minutes while it is being heated at a rate fast enough to reach incipient fusion just before discharge. At this point the material softens, coalesces, and appears to have the consistency of chewing gum. Escaping gases are trapped and form a vesicular structure with an increase in volume of about 50 percent. The sticky mass is discharged and cooled and thereafter is crushed and screened to the various aggregate sizes. Insufficient heating and fusion lower the crushing strength of the aggregate, and overburning causes more complete fusion and loss of part of the cellular structure. In properly burned Haydite, particles as fine as 48-mesh exhibit the same typical vesicular structure as shown by the large sizes. At plants using raw material containing excess calcium, water is added to the kiln discharge to hydrate any quicklime that may have been formed in the process.

One fine and two coarse sizes of aggregate are available for use in general concrete work. The fine or "A" size is graded from 3/16-inch to dust and is suitable for the sand size in precast concrete products and structural concrete. The intermediate or "B" size consists of 1/2- to 3/16-inch particles and is used as coarse aggregate in precast units. Coarse or "C" size contains 3/4- and 3/16-inch material and is used as coarse aggregate in structural concrete. Other gradings generally available are "CX," from 3/4-inch to dust; "BX," 1/2-inch to dust; "F.F.," 3/8-inch to dust; and "A.A.," 8-mesh to dust. In addition, special gradings are prepared on demand for particular uses. Weight of Haydite aggregate ranges from about 60 pounds per cubic foot for the "A" size (fine) to approximately 40 pounds for the "C" size (coarse). An all-Haydite concrete for general use weighs 90 to 100 pounds per cubic foot, and one using Haydite coarse aggregate and common sand for fine aggregate weighs 100 to 112 pounds. Special insulating and floor-fill all-Haydite concrete weighs 60 to 75 pounds per cubic foot. A standard precast masonry block 8 by 8 by 16 inches, using Haydite aggregate, has an average weight of 27 pounds[9/].

Haydite concrete mixes exhibit in marked degree all common properties of lightweight aggregate concretes and as a result have been adopted widely in many types of construction. When first introduced commercially the aggregate was used only in structural concrete, and it was not until 1924 that Haydite was used for the first time in manufacture of precast units. The latter use now consumes by far the major portion of annual production.

Because of its low heat conductivity (value of "K" for 80-pound concrete at 75° F. is approximately 2.5), the use of Haydite concrete has been developed as an insulating material suitable for temperatures up to 2,200° F. (1,100° C.).

9/ Cleary, John B., Haydite Manual: American Aggregate Co., Kansas City, 1940, 72 pp.

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Although the Haydite aggregate generally fuses between 2,200° and 2,300° F. (1,200° and 1,250° C.), the concrete does not fail completely until about 2,400° F. (1,300° C.). For high-temperature insulating mixes the cementitious material usually is an alumina cement, but ordinary portland cement also is claimed to have been used successfully under certain conditions. Increased thermal insulation and decreased unit weight may be attained with minimum loss of strength by substituting expanded vermiculite for part of the Haydite aggregate. This relatively new and specialized use for Haydite has resulted in shipments for unusually long distances - for instance, its exportation to South American countries. In addition to high-temperature insulating uses, Haydite concretes have been employed in direct contact with heat in such installations as baffle plates in boilers, in oil-distillation equipment, in Cottrell dust precipitators, in industrial stacks, and as lining in all except the hottest part of a rotary kiln producing Haydite.

Haydite sand graded between 4-mesh and dust for use in plaster and stucco is said to yield better thermal and acoustical values than ordinary sand. Recently, experiments[10/] have demonstrated the suitability of Haydite aggregate as the "medium" in soilless culture and propagation of plants, a use that may develop into a tonnage market for certain grades of the aggregate.

Sintered Aggregates

Several patented processes (U. S. Patent 1,786,713 and others) cover the expansion of clays and shales to lightweight materials by the use of sintering machines in which the basic principle of expansion operates in a manner similar to that obtained in rotary kilns. In these processes the clay or shale is ground to minus-1/8-inch or smaller size and mixed with granulated coal and enough water to form a crumbly mass. One process employs furnace cinders in proportions of 25 to 50 percent of the mix instead of coal. The material is charged to the moving grates of the sintering machine, struck off to a desired thickness, and a draft of air is drawn downward through the layer. Fuel particles near the upper surface are ignited by a downward-directed flame, and thereafter combustion is said to proceed without flame in a thin zone in which the clay or shale is expanded. After discharge, the lightweight sinter is crushed and graded into aggregate sizes.

The use of sintering machines apparently would be particularly adaptable to the expansion of coal-mine slates and culms, which ordinarily contain more than enough combustible to burn under forced draft. An anthracite-mining company in Pennsylvania experimented at length on expanding breaker wastes by sintering, but the process never was adopted. In New York City an

10/ Wagner, Arnold, Gravel and Cinder Culture for Greenhouse Flowering Crops: Div. of Floriculture, Ohio State University.

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experimental plant has produced a lightweight aggregate named "Corlite" by sintering chemically treated anthracite ashes mixed with a flux. In Chicago, "Lytag," a lightweight aggregate, was made experimentally on a sintering machine. However, so far as known none of the sintered aggregates has been made on a commercial scale.

Processed Diatomaceous Shales

Low-grade diatomite and diatomaceous shales have been processed for use as lightweight aggregate in ordinary concrete by crushing to minus-1-inch size, screening to remove fines, spraying with oil, and burning in a rotary kiln at a maximum temperature of about 1,100° C. (2,000° F.). At this temperature organic impurities are burned out, and the clay present in the raw material probably is expanded so that the product weighs 40 to 50 pounds per cubic foot. Discharge from the kiln is screened into three sizes: Sand, minus-4-mesh; pea gravel, 8-mesh to 3/8-inch; and coarse aggregate, plus-3/8-inch. Processing plants manufacturing this type of diatomite aggregate are located in California, where it is available under the trade names "Diacrete" and "Raylite."

An oil-impregnated diatomaceous shale has been made in California by a patented process (U. S. Patent 2,112,380, March 29, 1938) into a lightweight aggregate called "Airrox." Raw shale, crushed and screened into sizes up to 1-inch, is mixed with ground limestone, and the mixture (95 percent shale and 5 percent $CaCO_3$) is fed to a rotary kiln 125 feet in length and 7 feet in diameter. Upon entering the high-temperature zone the shale fragments fuse on the surface and pick up a coating of lime, which prevents the pieces from agglomerating and also combines with silica of the shale to form a thin shell of calcium silicate. The fragments become soft throughout, and evolved gases expand the interiors to produce vesicular structure. The tumbling action of the kiln rounds the fragments so that the discharge has a smooth appearance, with a dense, impervious shell. The aggregate weighs 35 to 40 pounds per cubic foot in a saturated, surface-dry, loose condition.

Expanded Loams

In the Scandinavian countries scarcity of natural lightweight substances such as pumice has caused lightweight aggregates to be processed from suitable loams. In the process plastic loams are pugged and fed directly to coal-fired rotary kilns, in which the material is vesiculated or expanded at 2,200° to 2,550° F. (1,200° to 1,400° C.). Kiln discharge is screened into three grades of aggregate - nut, pea, and grit. Two plants in Sweden and one in Denmark are reported[11] to be making this type of aggregate.

11/ Zement, vol. 29, No. 8, February 22, 1940, pp. 91-92.

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Expanded Slags

Specially processed or expanded slags are made by treating molten blast-furnace slags with controlled quantities of water. Too much water produces granulated slag, which is not strong enough for use as aggregate, and not enough water increases the weight of the product. Techniques of manufacture are patented and differ widely, as some slags are expanded in pits dug in the ground, while others are made in intricate machines. The expanded slags exhibit all the desirable properties common to lightweight aggregates and have a pleasing light color that appeals to the manufacturer and purchaser of masonry units.

Pottsco

The expanded-slag aggregate "Pottsco" was marketed first in 1928 in the Chicago area. It is made by a simple process covered in U. S. Patent 1,816,988, which is said to cover also the general use of expanded slags in concrete for building purposes. At present this aggregate is made in plants at Birdsboro and Pittsburgh, Pa.; Buffalo and Troy, N. Y.; Cleveland and Youngstown, Ohio; and Gary, Ind.

The method of manufacturing Pottsco differs from plant to plant. In some the molten slag is run into pits shaped as truncated cones about 15 feet deep and with approximate diameters of 20 feet at the top and 15 feet at the bottom. One ladle of slag is enough for a pit. A roughly determined quantity of water is run into or allowed to seep into the pit before the salg is added. The approximate ratio of slag to water required to produce a product of proper texture is about 3:1. The temperature of the slag entering the pit is probably about 2,600° F. (1,425° C.). The water becomes steam, which apparently is the active agent in vesiculating the slag. The material in the pit, which resembles volcanic pumice or scoria, is cooled and removed by means of a clamshell bucket.

A more complicated means of making Pottsco is to allow the molten slag to fall on a tilted, revolving, circular table set at the head of an open-end, water-jacketed trough. The slag stream, first broken up by the table, encounters a water spray and is expanded on its way through the trough. The partly expanded slag discharges directly onto a pan conveyor, passes under several water sprays, and the completely-expanded slag falls onto the stock pile. This method affords close visual control of expansion and yields a more uniform product than the pit method.

Pottsco aggregate is available in two standard grades: "B," which is sizes between 1/2- and 1/4-inch, and "C," which is minus-1/4-inch material. The coarse size weighs about 45 pounds per cubic foot and is used chiefly as

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coarse aggregate in structural concrete. The fine size, "C," weighs approximately 55 pounds per cubic foot and is used either as the sand-size aggregate in poured concrete or for the manufacture of precast units. The concrete weighs 90 to 100 pounds per cubic foot, and a standard 8- by 8- by 16-inch unit weighs about 30 pounds. Output of Pottsco has increased markedly since the depression of 1932-33, and at present nearly the entire production is consumed by the precast-unit industry.

Tuff-Lite

A vesiculated slag named Tuff-Lite was available commercially at Nashville, Tenn., until the beginning of 1940, when production ceased. Raw material consisted of slag from a blast furnace treating phosphate rock. In the process of manufacture (U. S. Patent 1,920,728) molten slag was poured from ladles into special machinery in which water and steam were used to expand the slag. Two stock sizes of aggregate were available - a coarse size containing particles 3/4- to 1/2-inch and a fine size ranging from 3/16-inch to dust. When dry-rodded, the coarse grade weighed 45 to 50 pounds per cubic foot and the fine size 75 to 80 pounds. Tuff-Lite concretes for insulating or floor-fill use had an average weight of 80 pounds per cubic foot. Structural concretes using Tuff-Lite aggregate weighed 100 to 110 pounds per cubic foot.

Waylite, Superock, and Waylite-Superock

These three lightweight aggregates are identical and are made from molten slag by the same patented process (U. S. Patents 1,483,241 and 2,023,511). They are available as follows: Waylite in Chicago, Ill., Superock in Birmingham, Ala., and Waylite-Superock in Bethlehem, Pa. Waylite was first known in 1931 but was not widely used until 1937. Since then output of the plants has increased considerably to meet the strong demand from the precast-unit industry.

In the process of manufacture molten slag flows from the blast furnace into the top of the Brosius machine (patented) at a temperature of about 2,500° F. (1,375° C.). The slag first hits a series of paddles that rotate horizontally about the center drive shaft. The paddles break the slag stream into small particles, which are thrown against a buffer plate on the outside shell, from which the particles fall onto a second series of horizontally-rotating blades. The same stages are repeated with this set of blades and again with a third set before the slag is discharged from the bottom of the machine. A manually controlled stream of water plays upon the blades and buffer plates and fills the machine with a mist that cools the slag to about 500° F. (250° C.) at discharge. The violent agitation plus the action of the steam expand the slag in its course through the machine. Discharge falls onto a pan conveyor, which transports the material to cooling storage, which is followed by crushing and grading.

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Two sizes of aggregate generally are stocked - a coarse size of particles between 1/2- and 3/16-inch and a fine size composed of minus-3/16-inch material. The coarse size has an average weight of 45 pounds per cubic foot and the fine size weighs 55 pounds. An all-Waylite concrete intended for use as floor fill weighs about 60 pounds per cubic foot. For structural purposes all-Waylite concrete weighs 90 to 105 pounds per cubic foot. Average weight of a standard 8- by 8- by 16-inch masonry unit is 30 pounds. Consumption of this group of aggregates has increased markedly since 1937.

Expanded Vermiculite

Vermiculite is a micaceous mineral that possesses the peculiar property of exfoliating when heated. Commercial utilization of this property has resulted in the development of an extremely lightweight insulating material that weighs only 6 pounds per cubic foot. One use of the sized material is for lightweight concrete-aggregate, which is available at expanding plants in nearly all sections of the country. Vermiculite ore is mined in Colorado, Montana, and North Carolina.

The aggregate is made by exfoliating (expanding) vermiculite ore specially selected for its toughness. Expanded material is cleaned and graded into aggregate sizes and in some instances is mixed in proper proportions with a mineral plasticizing agent. Weights of vermiculite concretes range from 31 pounds per cubic foot in floor fills to 80 pounds per cubic foot in structural concretes. In addition to having the usual properties of lightweight aggregates, vermiculite particles are said to partly absorb any expansive or contractive forces in the concrete. The aggregate has been used in all types of precast building units, floor fills, structural concretes, and as insulating material for temperatures up to 2,200° F. (1,200° C.). The fine sizes of carefully-graded, expanded vermiculite are used instead of natural sand to make lightweight acoustical and heat-insulating plasters.

MARKET SUMMARY

Before virtual stoppage of construction by economic conditions from 1932 through 1934, consumption of lightweight aggregates largely comprised cinders, which were used extensively in both structural concrete and for manufacture of precast units. Air-cooled slag and Haydite were important factors in those markets where supplies were available, and demand for Pottsco, which had just been introduced, was reported to be increasing steadily. Several other processed aggregates had been patented but none had advanced beyond experimental stages. Natural lightweight aggregates were not available commercially at that time and only occasional local use was made of them.

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The strong revival of the building industry from this depressed condition to the present time was accompanied by greatly increased demand for all commercial lightweight aggregates, due largely to their wide acceptance for use in precast masonry units. From a tonnage viewpoint, cinders continued to prevail in the current lightweight field, principally by reason of widespread availability and low price. Notable gains in consumption were reported for air-cooled slag, Haydite, and Pottsco wherever available, and plants processing them were set up in several new market areas. A new expanded-slag aggregate entered commercial status and became available in three widely separated markets under the names Waylite, Superock, and Waylite-Superock. Likewise, the natural lightweight aggregate, pumice, was made available on a commercial scale and became established in several areas. Diatomite and expanded vermiculite now are sold for concrete aggregate, although their markets for this purpose are limited by price and availability to rather special lightweight or insulating uses.

As demand for lightweight concretes is centered almost entirely in building construction, it is natural that facilities to produce lightweight aggregates would be located in or near the centers of building activity, which are the densely populated metropolitan areas. This segregation of production has set up well-defined market areas in which generally two or more lightweight aggregates are available and competing with each other.

In the extensive building-material markets of the eastern coastal area from Boston to Norfolk, demand for lightweight aggregates has long been filled almost entirely with cinders, which, in some cities, have little or no competition. Somewhat limited quantities of air-cooled slag from furnaces in New Jersey and eastern Pennsylvania are available for the New York and Philadelphia markets, and this aggregate is reported to be well-established in the Baltimore area, where supplies are adequate. Processed aggregates first became available several years ago in the New York and Philadelphia areas when plants producing Pottsco and Waylite-Superock started operations in southeastern Pennsylvania. Up to the present, expanded-shale aggregates have entered the eastern markets only as occasional shipments of Haydite for special uses. However, a Cel-Seal plant reportedly is planned at a central New Jersey location easily accessible to both New York and Philadelphia markets.

Ample supplies of lightweight aggregates are available in the Buffalo-Rochester area, for cinders, air-cooled slag, Haydite, and Pottsco are competing here. An identical situation exists in Cleveland, where the same four aggregates have been available in commercial quantities for a number of years. In the Pittsburgh district, local supplies of cinders, air-cooled slag, and Pottsco continue to satisfy the demand for lightweight concrete materials.

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The similar needs of the Detroit market are filled by the locally available cinders and air-cooled slag. The Chicago area is better-supplied with lightweight aggregates than any other market in the country, and demand is said to be increasing steadily, especially for the processed materials. In this area, cinders, air-cooled slag, Haydite, Pottsco, and Waylite are firmly established as materials for lightweight construction. Requirements for lightweight materials in both the St. Louis and Kansas City regions are filled from locally available supplies of cinders and Haydite.

In nearly all southern metropolitan areas, only limited quantities of lightweight aggregates are available. The outstanding exception, the Birmingham district, has ample supplies of cinders, air-cooled slag, and Superock, which have all become firmly established structural materials. Air-cooled slags also are available in the Roanoke, Knoxville, and Nashville markets, in which cinders are the only competing lightweight aggregate. Cinders are used for building purposes in a number of other southern cities where local supplies may be had.

In the Rocky Mountain States, pumice and other lightweight volcanics are easily available to practically all centers of building activity and are used commercially in Albuquerque, Denver, and Salt Lake City. Air-cooled slag and cinders are competing with pumice in the lightweight markets of the Denver area. On the Pacific coast, pumice is the most widely used lightweight aggregate. It is prominent in the San Francisco area, where it is sold in competition with Gravelite and Haydite under the trade name of Basalite. In addition to pumice, the diatomaceous materials--Diacrete, Raylite, and Airrox--are available in the Los Angeles area. Haydite, pumice, and cinders comprise the accessible lightweight aggregates in the Seattle market.

Although the lightweight materials are relatively new in concrete-work, it is evident from the foregoing that they already are firmly established and widely accepted in all parts of the country as giving satisfactory and proven service. More extensive utilization of these aggregates may be forecast from the growing recognition of the desirable properties that they impart to concrete mixtures, especially those properties of effective heat- and sound-insulation that are increasingly important in residential building.

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